Bulletin of the Seismological Society of America, Vol. 85, No. 1, pp. 361–374, February 1995

Global Positioning System Resurvey of Southern California Seismic Network Stations

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Abstract Systematic errors in travel-time data from local earthquakes can sometimes be traced to inaccuracies in the published seismic station coordinates. This prompted a resurvey of the stations of the Caltech/USGS Southern California Seismic Network (SCSN) using the Global Positioning System (GPS). We surveyed 241 stations of the SCSN using Trimble and Ashtech dual-frequency GPS receivers and calculated positions accurate to 3 m using differential positioning from carrier phase measurements. Twelve percent of the stations that were surveyed were found to be mislocated by more than 500 m. Stations of the TERRAscope and USC networks were also surveyed, as well as a network of portable seismic stations deployed shortly after the 1992 Joshua Tree and Landers earthquakes. The new coordinates and the offsets from the old coordinates are given below. The new coordinates are being used in SCSN locations as of 1 January 1994.

Introduction

We would like to be sure that the accuracy of our seismic station coordinates is well below the resolution of our seismic data. Errors in published station coordinates greater than 500 m can be seen quite easily in local earthquake travel-time data. An example is shown in Figure 1, where travel-time residuals show a systematic azimuthal dependence because of a station location error of 770 m. Errors on the order of 100 m are not as easily detectable in the raw travel-time data but probably cause artifacts in processing schemes such as tomography that average large datasets to find systematic variations of travel time as a function of space. Real-time absolute GPS positions, frequently quoted as having accuracies of less than 50 m horizontally, would probably be sufficient for present day applications of the SCSN dataset. Unfortunately, past experience in seismic experiments has shown that this accuracy cannot be reliably attained, usually because of a less than optimal GPS satellite geometry. We use differential GPS positioning from carrier phase measurements to find positions accurate to 3 m, even though this is more accurate than we presently need.

Surveying Procedure

Differential positioning requires simultaneously running two GPS receivers with one of the receivers located at a known benchmark and then calculating the position of the field receiver relative to the benchmark. The Permanent GPS Geodetic Array (PGGA), a network of continuously operating GPS receivers in southern California, provided the fixed reference receivers (Bock, 1993) with baselines of about 50 to 100 km for stations west of the San Andreas and baselines of about 100 to 300 km for stations east of the San Andreas. We recorded data with one GPS receiver at each of the seismic stations during the continuous operation of the PGGA. This receiver was one of a Trimble SSE dual-frequency *P*-code receiver, a Trimble SST dual-frequency codeless receiver, or an Ashtech LM-XII dual-frequency codeless receiver. We recorded a minimum of a half-hour of data sampled every 2 min with a minimum of five GPS satellites visible during the observation period. Less than a half-hour of data gave significantly poorer results. The carrier phase data (not just the pseudorange data normally used to get the real-time absolute position) were postprocessed on a Sun workstation using the GAMIT software (Dong and Bock, 1989). One reason we chose the GAMIT software over other available software (i.e., TRIMVEC provided by Trimble and GPPS provided by Ashtech) was because the interactive data editor allowed us to verify that we had collected high-quality data. GAMIT also allowed us to easily use the GPS satellite orbits calculated at Scripps Institute of Oceanography (Fang *et al.*, 1992), and easily automate the processing for our survey because of our familiarity with the Unix system under which the GAMIT software runs. Geodynamic applications of the GPS have shown that this method can produce millimeter accuracy results in differential positioning, much higher resolution than required for seismic applications. In spite of the short time series we recorded, we achieved an accuracy of 2 to 3 m. After the initial effort of streamlining the processing operations, the total processing time, including interactive data editing, was usually about 45 min for each field day. With the GPS satellite constellation that was available during daylight hours in March through August 1993, we were usually able to make measurements at three to four sites per day per receiver.

For the seismic stations that are currently operating, we attempted to locate the GPS antenna directly over the vertical seismometer. Seismic stations are frequently well hidden to prevent vandalism and unfortunately this means they usually have limited sky visibility. For these stations, the antenna was located in a clearing and the distance and azimuth from the seismometers to the GPS antenna was locally surveyed with a compass and measuring tape with an error of less than 2 m. Locations of seismometer components other than the vertical were surveyed locally when the distance separating them is greater than 10 m. The local survey error was as much as 20 m for seismic stations that are no longer operating and for which we thus have no evidence of the exact location of the seismometer.

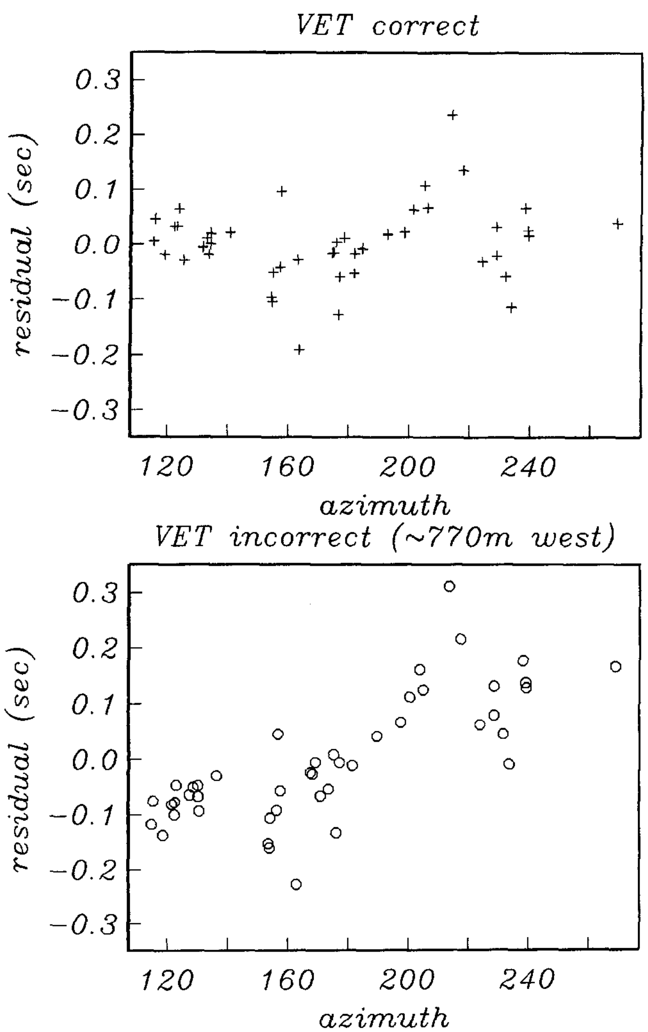

Figure 1. Comparison of earthquake travel-time residuals as a function of azimuth for the correct and incorrect station coordinates at station VET of the Southern California Seismic Network (SCSN). This shows that mislocations as small as 770 m can easily be seen in the data and could be mistaken for lateral variation in seismic velocity.

Accuracy of GPS Differential Positioning

We performed a test of the accuracy given the constraints of our experimental setup by recording data at a benchmark of known location in Glendale (Glendale–JPL baseline length about 10 km) on two different days and processing the data with the TRIMVEC software as well as the GAMIT software. The difference between the measured location and the actual location (labeled "error" in Table 1) was less than 1.2 m for all tests. The standard error (labeled ("σ" in Table 1) in some cases underpredicts the true error. In our processing of the data, we required that the standard error of the calculation was less than 3 m for all three components or we remeasured the station. The results are given to show that the procedure we used was sufficient for the positioning accuracy we need. The errors are inherent to the GPS technique (Larson *et al.*, 1991), but are enlarged as a result of the short time series we recorded. The short time series was the limiting factor in the accuracy rather than the software used.

Accuracy of Real-Time GPS Positions

In seismic experiments, real-time absolute GPS positions read directly from the GPS receiver in the field are sometimes used under the assumption that the advertised 30 to 50-m accuracy can be achieved. We find this accuracy to be underestimated in practical situations. This is a result of the Department of Defense intentional degradation of the GPS signal at unannounced time periods (selective availability and anti-spoofing) and inadequate satellite geometry. The vertical component is inherently more poorly resolved because of the geometry and has an accuracy of 100 m at best. We compared the answers we obtained-using our postprocessing differential positioning with the lowest PDOP real-time pseudorange position recorded during the half-hour observation period (PDOP = position dilution of precision, the theoretical decrease in accuracy due to the satellite-receiver geometry). Four percent of the time, the position was different by more than 500 m and sometimes as much as 7 km (horizontally), usually because of a less-than-optimal geometry. The remaining 96% of the time, the standard deviation of the difference in positions was 55 m horizontally and 100 m vertically. This is an optimistic estimate of the accuracy of the method because of the great care taken in the field to record during an optimal time period. Also, we used geodetic quality Trimble and Ashtech receivers, which have better tracking capabilities than the more portable handheld GPS receivers that are popular for seismic applications. GPS surveys without careful preplanning (especially during typical seismic field deployments for earthquake aftershock studies, for example) will achieve this accuracy a smaller percentage of time.

Pseudorange absolute GPS positioning, when averaged over a period greater than 2 hr, however, can achieve the required horizontal accuracy of high-resolution seismic experiments. The vertical position can then be read from a topographic map given the GPS derived latitude and longitude. We compared the results of this type of survey (Scott, 1992) for a small subset of the SCSN stations to the differential postprocessing positions. We find that the standard deviation of the errors of this averaging method is 6 m horizontally and 8 m vertically and the maximum error is 20 m horizontally and 30 m vertically. The disadvantage of this method is that there is more frequent Department of Defense degradation of the GPS signals now than there was when this 1989 survey took place. There is also a large chance of transcription errors when relying on the topographic maps. These comparisons are summarized in Table 2. The prospect of differential real-time positions from handheld receivers is the most ideal for seismic applications and though it is possible, it has not yet been developed to the point to be practically useful. The major difficulty is that the operators of the two handheld receivers must be in voice communication in order to manually type corrections into the receivers.

A Note on Coordinate Systems

Geodetic coordinates output by GPS receivers are most frequently given in WGS-84 coordinates with height relative to the WGS-84 reference ellipsoid (Defense Mapping Agency, 1987; Soler and Hothem, 1988, 1989). The WGS-84 reference frame by definition coincides with the NAD-83 reference frame commonly used by surveyors, though small differences <1 m exist that reflect small, random regional distortions present in the NAD-83 horizontal datum. This can cause some confusion since most seismic stations coordinates are usually given in NAD-27 coordinates (the coordinate system used on USGS topographic maps) with the elevation above sea level. For the stations in southern California, the WGS-84 (and

Table 1
Differential Positioning Accuracy

Software	Observation Time	Error *N* (m)	Error *E* (m)	Error *H* (m)	σ_N (m)	σ_E (m)	σ_H (m)
GAMIT	40 min	0.6943	−1.1178	−1.0660	0.1261	0.2300	0.5244
GAMIT	25 min	0.7288	−0.7196	−0.8110	1.0361	2.6422	1.8547
TRIMVEC	25 min	1.0414	−0.7621	−0.2021	—	—	—

Table 2
Summary of GPS Methods Used in Our Comparison

Method	Processing Scheme	Receiver Type Used	Observe Time	Sats in View	Horiz. Acc.	Vert. Acc.	% Stations w/Error > 500 m
Differential positioning	dual-freq. phase postprocess i.e., GAMIT	Trimble SSE Trimble SST Ashtech	1/2 hr	≧5	2 m	3 m	0%
Differential positioning	dual-freq. phase postprocess i.e., TRIMVEC	Trimble SSE	1/2 hr	≧5	2 m	3 m	0%
Absolute positioning	pseudorange real time no averaging	Trimble SSE	1/2 hr	≧5	55 m best PDOP	100 m best PDOP	4%
Absolute positioning	pseudorange averaging Topo height	Motorola handheld	2 to 7 hr	4 (max possible)	6 m	8 m	0%
Best Bet for the Future:							
Differential positioning	pseudorange real time	handheld receivers	real time	≧4	5 m(?)	10 m(?)	(?)

*Position dilution of precision.

NAD-83) coordinates are approximately 76 m west and 3 m north of the NAD-27 (topo) coordinates. There is less than 8-m variation of these offsets over the range of the seismic network. The height above the reference ellipsoid is the elevation above sea level plus the geoid height, and the geoid height is approximately -32 ± 60 m over most of southern California. We present our results in the WGS-84 system and heights above the WGS-84 reference ellipsoid with the understanding that this superior reference ellipsoid will eventually come into more popular use as GPS becomes a more frequently used tool. We assume that differences between the NAD-83 coordinates and WGS-84 coordinates can be neglected given the 3-m accuracy of the results. We transformed the prior station coordinates to the WGS-84 reference frame before comparing the results of our survey. For consistency we have transformed the coordinates of SCSN stations we did not resurvey into the WGS-84 coordinate system and these are available along with the surveyed station coordinates from the Southern California Earthquake Center (SCEC) Data Center.

Results of the Survey

We surveyed 241 stations of the SCSN network, 14 TERRAscope stations, 22 USC stations, 23 portable seismic stations for the 1992 Landers earthquake deployment, and 11 portable seismic stations for the 1992 Joshua Tree earthquake deployment. We compared the GPS survey locations for SCSN stations with the station list from the USGS data base in Pasadena, which is the most complete list of all currently operating and historic stations of the SCSN (Lisa Wald, personal comm.). A subset of this list containing only the currently operating stations is used in the actual location process of the SCSN. The statistics of the differences between the GPS survey coordinates and the previously estimated coordinates are given in Table 3. The differences in coordinates are shown graphically in Figure 2 for horizontal differences and Figure 3 for vertical differences. Note that in Figure 2, the offset was not plotted for station differences greater than 5 km, which in most cases can be attributed to typographical or transcription errors. The SCSN network coordinates taken from the USGS data base in Pasadena were originally determined from topographic maps. The GPS survey locations for the TERRAscope, Joshua Tree, and Landers stations were compared to station lists at the SCEC Data Center. The TERRAscope coordinates originally were taken from the SCSN list for colocated stations, and taken from preliminary real-time absolute GPS positions from this survey for the newer stations. The coordinates for the Landers and Joshua Tree deployments were originally taken from a combination of topographic maps and hand-held real-time absolute GPS positions. The results shown in Table 3 give a realistic assessment of station coordinate accuracy for typical networks. The relatively poor quality of Landers deployment coordinates can be understood given the hectic nature of an experiment that took place within 12 hr of a magnitude 7.3 earthquake. The errors in locations of three SCSN stations greater than 100 km were simply typographical errors in integral degrees in the master data base list and do not exist in the station list subset used for routine locations, where they would have easily been noticed and corrected. The 64-km error of two stations was due to confusion between site names and existed only in the master data base list and not the subset used for locating. The 15-km error of one station was introduced after this study was begun in the process of verifying the coordinates from a topographic map and making a transcription error of 1 min, and only existed for a short period of 3 months before it was detected. The remaining errors in SCSN station locations, the largest of which was 10 km, went undetected in both lists. This is conceivable because of the automatic downweighting of very high residuals in the location procedure. SCSN station mislocations on the order of 2.5 km have been detected and corrected in the past (Given *et al.*, 1989; Scott, 1992). Errors at this level are easily detected from azimuthal variation of travel-time residuals, but this requires detailed analysis of a localized subset of residuals at each individual station, a task that is not routinely performed for the whole network. These errors can sometimes be traced to transcription errors, miscommunica-

Table 3
Accuracy of Original Coordinates

Network	Number of Stations	σ_N (m)	σ_E (m)	σ_H (m)	Max Horiz Error (m)	Max Vert Error (m)	% Stations Error > 500 m
TERRAscope	14	99.2	135.1	58.1	712.3	812.0	7%
USC	22	25.7	47.6	150.2	110854.0*	952.4	18%
Joshua Tree	11	81.8	51.5	—	15021.7	56.8	9%
Landers	23	200.5	107.1	47.0	15489.5	173.2	43%
SCSN	241	84.8	84.2	72.6	554081.0*	982.1	12%

*Typographical errors of an integral number of degrees in the horizontal components in the SCSN version of the station lists.

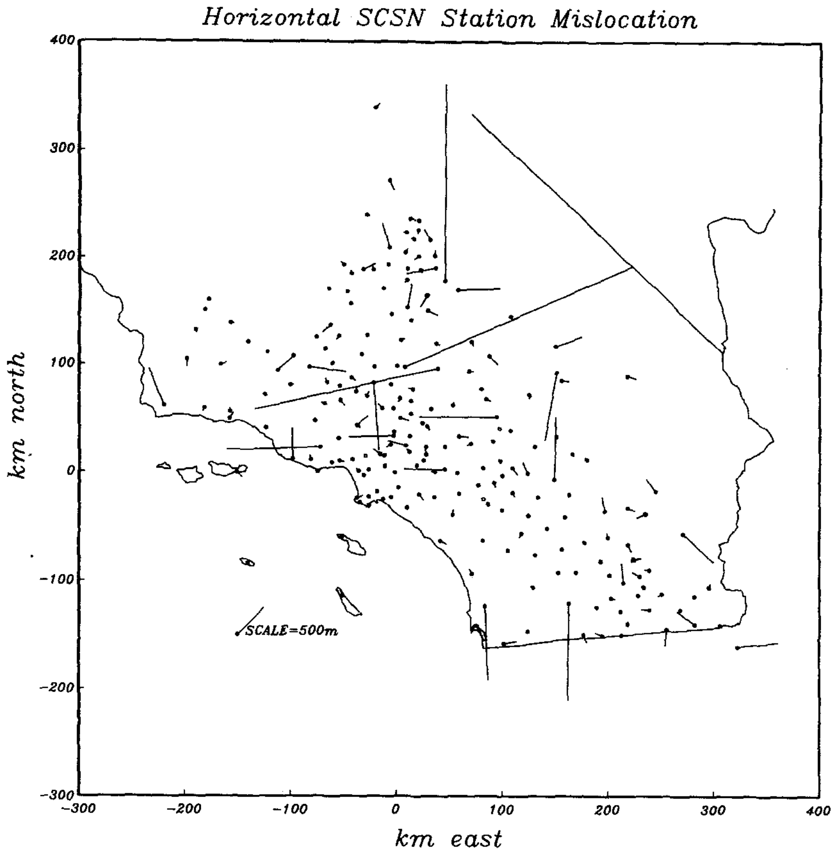

Figure 2. Horizontal station mislocation for the SCSN. The circle shows the new station location and the vector shows the difference between the old and new station coordinates. The length of the vector is proportional to the size of the mislocation error at the station, with the scale given at the left for a 500-m error. Errors larger than 5 km, which were in most cases due to typographical errors, are not shown since they exceed the scale of the plot.

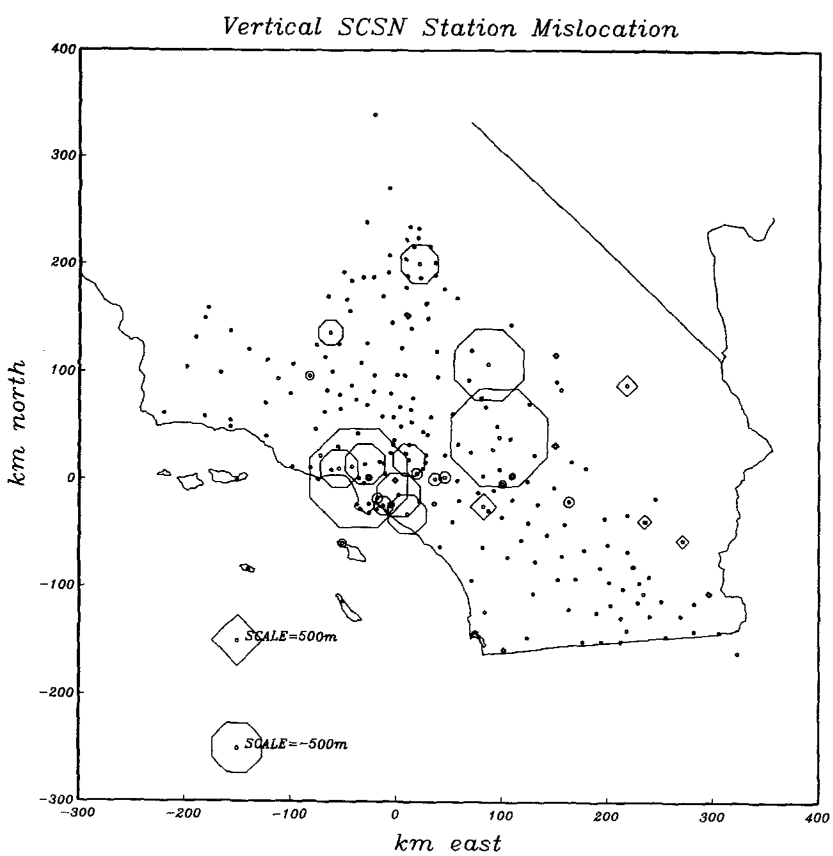

Figure 3. Vertical station mislocation for the SCSN. The size of the symbols plotted at the station locations are proportional to the size of the vertical mislocation error, with positive differences indicated by octagons and negative differences indicated by diamonds, and the scale given at left for a 500-m error. The large errors in the Los Angeles Basin area are due to a miscommunication on whether the depths of the borehole seismometers were already subtracted from the elevation of the station when the coordinates were originally entered into the SCSN station list.

Table 4
TERRAscope Stations (WGS-84 Reference Frame) Coordinates Available from the Computer scec.gps.caltech.edu

Station	Latitude (°)	Longitude (°)	Height (m)	ΔN (m)	ΔE (m)	ΔH (m)
BAR	32.68005	−116.67215	496	−6	14	51
DGR	33.64996	−117.00948	609	4	44	90
GSC	35.30176	−116.80572	954	−6	65	35
ISA	35.66278	−118.47403	817	57	66	17
MLA	37.63014	−118.83611	2134	95	186	35
NEE	34.82482	−114.59942	139	−202	312	−139
PAS	34.14844	−118.17113	257	62	−30	37
PFO	33.61151	−116.45935	1245	10	70	42
RPV	33.74329	−118.40426	64	56	70	−64
SBC	34.44076	−119.71492	61	104	148	28
SMT	32.94892	−115.72031	3	9	29	−3
SVD	34.10645	−117.09825	574	−215	68	25
USC	34.01916	−118.28597	17	4	61	42
VTV	34.56058	−117.32961	812	712	−311	−812

Table 5
USC Network Stations (WGS-84 Reference Frame) Coordinates Available from the Computer scec.gps.caltech.edu

Station	Latitude (°)	Longitude (°)	Height (m)	ΔN (m)	ΔE (m)	ΔH (m)
ALH (ZNE)	34.01953	−118.28377	20	−19	−652	−12
CIW (ZNE)	33.46566	−118.55152	87	−27	−138	−58
DH1 (ZNE)	34.01236	−118.38771	−4	40	−120	13
DH2 (ZNE)	34.01236	−118.38771	−420	−110854*	−119	−952
DHB (ZNE)	34.01236	−118.38771	−1437	40	−120	−15
FLA (ZNE)	33.87148	−117.97646	−441	−8	−49	−416
FMA	33.71828	−118.28485	−10	13	−46	4
GFP (ZNE)	34.13165	−118.31978	339	−17	15321*	−380
IPC (ZNE)	33.97048	−118.33525	23	27	−70	24
LCL (ZNE)	33.83999	−118.19521	−110	−28	−73	−88
LNA (ZNE)	33.78811	−118.05000	−28	32	−61	−10
LNA	33.78811	−118.05007	−95	31	−55	−42
LOM	33.79567	−118.28013	−202	−30	−50	8
MSH (ZNE)	34.01893	−118.29087	16	−25	648	−9
PVP (NE)	33.78939	−118.40199	202	38	28	−5
PVPZ	33.78939	−118.40199	109	38	28	30
RCP1	33.77730	−118.13345	−32	11	−83	−9
RCP2	33.77730	−118.13345	−117	11	−83	−9
RCP (ZNE)	33.77731	−118.13343	−26	10	−84	−9
SATM	33.70796	−117.89143	−420	12	−83	−367
SC1 (VNE)	34.01916	−118.28598	17	−11	−95	−42
SC2 (VNE)	34.01916	−118.28598	17	−11	−95	−42
SC3 (VNE)	34.01916	−118.28598	17	−11	−95	−42
TPRM	34.09285	−118.58780	335	−14	8	−357

*Typographical errors in the SCSN version of the station list.

tion, or uncertainty due to flat topography, but the reason for some large errors remains a mystery. The resurveyed station coordinates of the TERRAscope, USC, Joshua Tree, Landers, and SCSN networks are given in Tables 4, 5, 6, 7, and 8, respectively, with the more than one component listed when applicable.

The new coordinates are being used in routine earthquake location by the SCSN as of 1 January 1994.

Conclusions

Large errors in station locations can cause problems in the analysis of seismic travel-time data because they cause biased travel-time errors that cannot be averaged out. They can also cause serious artifacts in tomographic inversions. These time errors become important for portable deployments even if absolute time is not known

Table 6
Joshua Tree Stations (WGS-84 Reference Frame) Coordinates Available from the Computer scec.gps.caltech.edu

Station	Latitude (°)	Longitude (°)	Height (m)	ΔN (m)	ΔE (m)	ΔH (m)
AQUA	33.93201	−116.38024	458	−37	130	—
BRCJ	34.06897	−116.39225	1233	−70	115	—
COVF	34.03018	−116.34824	1638	−75	160	—
DWSR	33.76583	−116.54607	162	−36	68	—
EDC1	33.91662	−116.32661	480	61	56	—
EDCY	33.90383	−116.33644	377	−36	87	—
EDOM	33.86961	−116.42984	454	24	77	—
HDVL	unsurveyed					
KEYV	33.92621	−116.18159	1515	32	146	—
LMVR	33.99293	−116.52411	406	110878*	86	—
SDCE	33.93469	−116.40435	416	200	233	—
UCVF	34.01077	−116.30596	1441	25	88	—

*Typographical errors in the SCEC data center version of the station list.

Table 7
Landers Stations (WGS-84 Reference Frame) Coordinates Available from the Computer scec.gps.caltech.edu

Station	Latitude (°)	Longitude (°)	Height (m)	ΔN (m)	ΔE (m)	ΔH (m)
BNJI	34.16248	−116.32100	827	−52	0	32
BRCC	34.07209	−116.39146	1207	−409	42	52
BRDO	33.82960	−116.14899	483	377	1480	126
CGTS	34.95141	−116.86389	694	−2009	1269	11
EDC2	33.91662	−116.32661	480	42	149	19
EORD	34.65607	−116.71799	1160	−1450	91	0
ERWL	34.23493	−116.79843	2102	1672	−144	−43
FIRE	34.04858	−116.57799	749	−64	91	42
FORF	34.08831	−116.92047	1596	−556	319	173
GPOE	34.42274	−116.71687	894	1138	815	20
GRAC	34.26680	−116.38818	913	22	108	−1
GRAV	34.18700	−116.71979	2454	−443	257	75
HILL	34.36135	−116.45415	891	71	96	28
IRON	34.61667	−116.56712	1152	36	10	4
JFRG	34.04566	−116.62153	862	−73	49	37
LADY	34.13062	−116.31390	811	199	15489	10
LPMA	34.36031	−116.41921	733	−1143	239	74
RIMR	34.18646	−116.46342	1099	−17	75	25
UCVF	34.01077	−116.30596	1441	25	88	42
UGGP	34.74988	−116.66058	857	1788	2525	−23
VIPC	34.01772	−116.19027	1246	−24	71	46
VVST	34.35963	−116.57893	912	−513	−6	3
YKNF	34.20749	−116.44573	1094	−54	159	−3

accurately if high-precision *S-P* times are going to be used.

We resurveyed 241 stations of the SCSN, the stations of the TERRAscope network, the USC network, and the stations deployed during the Landers and Joshua Tree aftershock sequences. Using differential GPS positioning from dual-frequency phase measurements we achieved an accuracy of 3 m. We found that approximately 12% of the 241 stations of the SCSN and 43% of the 23 Landers deployment stations were mislocated by more than 500 m. The new coordinates are listed in the following tables. In order to avoid possible propagation of typographical errors, users are encouraged to retrieve the coordinates from the Southern California Earthquake Center (SCEC) Data Center computers (scec.gps.caltech.edu) in the file /export/scec/data1/stations/SCSNstatlist. This list includes coordinates for unsurveyed stations as well as the stations surveyed in this study. There is an ongoing effort to resurvey the remaining more remote stations of the SCSN. The new coordinates are being used

Table 8
SCSN Stations (WGS-84 Reference Frame) Coordinates Available from the Computer scec.gps.caltech.edu

Station	Latitude (°)	Longitude (°)	Height (m)	ΔN (m)	ΔE (m)	ΔH (m)
ABL	34.84845	−119.22497	1975	264	298	−36
ADL	34.55581	−117.41804	868	59	20	−12
ARBE	34.00431	−117.60540	308	6	−69	−131
ARBI	34.00431	−117.60540	308	6	−69	−131
ARBJ	34.00431	−117.60540	308	6	−69	−131
ARBK	34.00431	−117.60540	308	6	−69	−131
ARBN	34.00431	−117.60540	308	6	−69	−131
ARBZ	34.00431	−117.60540	308	6	−69	−131
ARB	34.00431	−117.60540	308	6	−69	−131
ARV	35.12687	−118.83008	236	32	−10	−11
AZUE	34.21980	−117.90121	1140	80	−334	−3
AZUI	34.21980	−117.90121	1140	80	−334	−3
AZUJ	34.21980	−117.90121	1140	80	−334	−3
AZUK	34.21980	−117.90121	1140	80	−334	−3
AZUN	34.21980	−117.90121	1140	80	−334	−3
AZUZ	34.21980	−117.90121	1140	80	−334	−3
AZU	34.21980	−117.90121	1140	80	−334	−3
BARE	32.68005	−116.67215	496	2	−28	6
BAR	32.68005	−116.67215	496	2	−28	6
BAT	33.45828	−115.84153	−53	86	−22	−12
BC2	33.65702	−115.46202	995	3	7	142
BC3	33.65484	−115.45309	1080	−67	−171	−29
BCH	35.18542	−120.08522	1109	−48	13	−12
BLK	35.08867	−117.21975	619	−73	38	−15
BLUZ	34.40686	−117.72779	1843	−19	11	−7
BLU	34.40686	−117.72778	1843	−18	11	−7
BMT	35.13641	−118.59723	1200	−64	−42	−6
BON	32.69732	−115.26902	−14	−303	−22	−21
BOO	34.87632	−117.91109	671	1888	4289	−12
BRAI	32.97899	−115.54936	−67	−9	−37	−14
BRAJ	32.97899	−115.54936	−67	−9	−37	−14
BRAK	32.97899	−115.54936	−67	−9	−37	−14
BRAZ	32.97899	−115.54936	−67	−9	−37	−14
BRG	33.17139	−116.17470	205	−16	−7	−33
BRSE	33.97145	−116.91265	1075	9	0	−82
BRSI	33.97145	−116.91265	1075	9	0	−82
BRSJ	33.97145	−116.91265	1075	9	0	−82
BRSK	33.97145	−116.91265	1075	9	0	−82
BRSN	33.97145	−116.91265	1075	9	0	−82
BRSZ	33.97145	−116.91265	1075	9	0	−82
BRS	33.97145	−116.91265	1075	9	0	−82
BRT	34.61206	−117.96354	757	−60	−27	−12
BTL	34.25698	−117.00521	2527	24	−39	−44
CAH	33.49296	−116.72386	1313	−64	−40	−17
CAL	35.10331	−117.94924	690	20	65	−11
CAV	35.05071	−116.34534	558	181	489	60
CBK	32.91580	−116.25226	355	−1799	−17	11
CCRE	34.36083	−116.94090	1383	−64861	−15400	−965
CCRJ	34.36083	−116.94090	1383	−64861	−15400	−965
CCRK	34.36083	−116.94090	1383	−64861	−15400	−965
CCRN	34.36083	−116.94090	1383	−64861	−15400	−965
CCRZ	34.36083	−116.94090	1383	−64861	−15400	−965
CCR	34.36082	−116.94090	1383	−64859	−15399	−965
CDY	34.83007	−116.33717	934	−1245	−225	−30
CFLI	34.33296	−118.02387	1560	−11	2	−18
CFLJ	34.33296	−118.02387	1560	−11	2	−18
CFLK	34.33296	−118.02387	1560	−11	2	−18
CFL	34.33296	−118.02387	1560	−11	2	−18
CFT	34.03521	−117.11189	648	0	7	−21
CIWZ	33.46566	−118.55152	87	−32	−60	−85
CJV	34.52978	−118.14450	1296	81	−77	0

Table 8—*Continued*

Station	Latitude (°)	Longitude (°)	Height (m)	ΔN (m)	ΔE (m)	ΔH (m)
CLC	35.81574	−117.59751	735	101	0	−11
CLIE	33.14029	−115.52658	−92	67	−141	−15
CLIN	33.14029	−115.52658	−92	67	−141	−15
CLI	33.14029	−115.52658	−92	67	−141	−15
CLME	34.09613	−117.72297	317	25	−2	−10
CLMI	34.09613	−117.72297	317	25	−2	−10
CLMJ	34.09613	−117.72297	317	25	−2	−10
CLMK	34.09613	−117.72297	317	25	−2	−10
CLMN	34.09613	−117.72297	317	25	−2	−10
CLMZ	34.09613	−117.72297	317	25	−2	−10
CLM	34.09613	−117.72297	317	25	−2	−10
CO2	33.84524	−115.34351	242	219	−178	−13
COA	32.86341	−115.12339	0	18	−3	−15
COK	32.84946	−115.72788	−50	−23	26	−13
COYZ	33.36296	−116.31114	218	−7	2	−20
COY	33.36296	−116.31114	218	−7	2	−20
CPE	32.89244	−117.10143	143	−1371	59	−13
CPMZ	34.15441	−116.19776	897	−41	27	−5
CPM	34.15442	−116.19771	897	−41	23	−5
CRG	35.24220	−119.72486	1169	−5	58	−8
CRR	32.88682	−115.96918	66	−45	7	−16
CSP	34.29796	−117.35833	1239	−11	185	−17
CTWZ	33.67728	−115.87214	504	271	−42	9
CTW	33.67728	−115.87214	504	271	−42	9
CWC	36.43988	−118.08016	1553	−175	86	27
DB2	33.73521	−117.06289	591	−18	7	−10
DBM	34.97877	−118.36107	1162	26	−26	0
DH1N	34.01236	−118.38771	−4	37	−42	−11
DH2N	34.01236	−118.38771	−420	−110860	−41	−980
DH2Z	34.01236	−118.38771	−420	−110860	−41	−980
DHBN	34.01236	−118.38771	−1437	−110842	−41	−982
DHB	34.01236	−118.38771	−1467	37	−42	−10
DTP	35.26742	−117.84581	908	8	−33	0
EDWI	34.88303	−117.99106	762	−2	3	−11
EDWJ	34.88303	−117.99106	762	−2	3	−11
EDWK	34.88303	−117.99106	762	−2	3	−11
EDWZ	34.88303	−117.99106	762	−2	3	−11
ELM	34.52638	−117.64064	954	−20	−33	−12
ELR	33.14747	−115.83335	−97	−7	7	−13
ELS	33.64698	−117.42812	790	99	12	16
EMS	32.73921	−114.98521	11	244	−315	−13
ERP	32.74311	−115.66354	−42	51	9	−14
EWCE	33.93724	−116.38216	466	14	34	0
EWCI	33.93725	−116.38214	466	14	32	0
EWCJ	33.93725	−116.38214	466	14	32	0
EWCK	33.93725	−116.38214	466	1161	32	0
EWCN	33.93724	−116.38216	466	14	34	0
EWCZ	33.93724	−116.38216	466	14	34	0
EWC	33.93724	−116.38216	466	14	34	0
FIL	34.42335	−118.83531	205	54	−4	−6
FLA	33.87148	−117.97646	−441	−12	27	−440
FLSI	34.97036	−117.03909	990	−168	161	−704
FLSJ	34.97036	−117.03909	990	−168	161	−704
FLSK	34.97036	−117.03909	990	−168	161	−704
FLS	34.97036	−117.03909	990	−168	161	−704
FMA	33.71828	−118.28485	−10	9	31	−21
FOX	34.74431	−118.23255	683	−1253	94	−10
FRK	33.40209	−115.63835	60	−133	69	−17
FTC	34.87151	−118.90020	986	−75	686	−86
GAVE	34.02248	−117.50492	262	6	−760	−120
GAVN	34.02248	−117.50492	262	6	−760	−120
GAVZ	34.02248	−117.50492	262	6	−760	−120
GAV	34.02248	−117.50492	262	6	−760	−120

Table 8—*Continued*

Station	Latitude (°)	Longitude (°)	Height (m)	ΔN (m)	ΔE (m)	ΔH (m)
GFPE	34.13165	−118.31978	339	−19	15399	−403
GFPN	34.13165	−118.31978	339	−19	15399	−403
GFPZ	34.13165	−118.31978	339	−19	15399	−403
GLAE	33.05107	−114.82779	514	75	35	63
GLAN	33.05107	−114.82779	514	75	35	63
GLA	33.05107	−114.82779	514	75	35	63
GRP	34.80481	−115.60705	978	−50	161	214
GSAA	34.13677	−118.12830	195	27	42	−7
GSAB	34.13677	−118.12830	195	27	42	−7
GSAC	34.13677	−118.12830	195	27	42	−7
GSAE	34.13677	−118.12830	195	27	42	−7
GSAI	34.13677	−118.12830	195	27	42	−7
GSAJ	34.13677	−118.12830	195	27	42	−7
GSAK	34.13677	−118.12830	195	27	42	−7
GSAN	34.13677	−118.12830	195	27	42	−7
GSAZ	34.13677	−118.12830	195	27	42	−7
GSC	35.30176	−116.80572	954	−9	−8	−8
GSTE	34.13677	−118.12830	195	27	42	−7
GSTN	34.13677	−118.12830	195	27	42	−7
GST	34.13677	−118.12830	195	27	42	−7
GTM	34.29460	−116.35600	836	11	−11	71
GVRE	34.04972	−118.11995	141	34	25	−9
GVRI	34.04970	−118.11997	141	35	27	−9
GVRJ	34.04970	−118.11997	141	35	27	−9
GVRK	34.04970	−118.11997	141	35	27	−9
GVRN	34.04972	−118.11995	141	34	25	−9
GVR	34.04972	−118.11995	141	34	25	−9
HAY	33.70736	−115.63892	413	−70	137	−21
HOD	34.83886	−117.24753	807	−2	79	−22
HOT	33.31440	−116.58236	1934	17	6	−28
HYS	34.86532	−117.56975	833	−773	−3452	−11
IKP	32.65012	−116.10948	906	−133	66	3
INDE	33.81673	−116.23040	324	554080	−10	−24199
INDN	33.81673	−116.23040	324	554080	−10	−24199
IND	33.81672	−116.23040	324	−55	−5	−16
ING	32.98865	−115.31024	−33	−27	−64	−13
IPCE	33.97048	−118.33525	23	24	7	0
IR2	34.38807	−118.39972	562	−43	49	2
IRC	34.38851	−118.40304	533	166	201	1
IRS	33.19086	−115.42904	−43	4	−83	−15
ISAE	35.66278	−118.47403	817	58	−14	−24
ISAN	35.66278	−118.47403	817	58	−14	−24
ISA	35.66278	−118.47403	817	58	−14	−24
JAW	35.31578	−118.04546	711	24	−19	7
JFS	35.35157	−117.67291	1393	−82	188	−3
JNH	34.44795	−117.95705	1289	−48	157	−16
JUL	33.04817	−116.61357	1260	25	−4	−13
KEE	33.63856	−116.65425	1359	17	−4	−14
KYP	34.10120	−118.88017	686	72	−17	−32
LAN	34.72683	−118.05177	684	19	−6	−9
LAQ	33.62798	−116.28051	−4	8	5	−5
LAV	34.76597	−116.28880	814	−13	137	42
LCLE	33.83999	−118.19521	−110	−31	4	−3
LCLN	33.83999	−118.19521	−110	−31	4	−3
LCLZ	33.83999	−118.19521	−110	−31	4	−3
LCL	33.83999	−118.19521	−110	−31	4	−113
LEO	34.63064	−118.30505	1025	77	48	4
LHU	34.67092	−118.41259	1000	84	6	−7
LJBE	34.59092	−117.84890	861	29	5	−6
LJBN	34.59092	−117.84890	861	29	5	−6
LJBZ	34.59092	−117.84890	861	29	5	−6
LJB	34.59092	−117.84890	861	29	5	−6
LLN	34.48532	−117.84648	981	22	12	−7

Table 8—*Continued*

Station	Latitude (°)	Longitude (°)	Height (m)	ΔN (m)	ΔE (m)	ΔH (m)
LNA	33.78811	−118.05007	−95	27	21	−67
LOK	34.72444	−119.09279	1538	7	54	−10
LOM	33.79567	−118.28013	−202	−33	27	−16
LRLI	35.47942	−117.68211	1315	−213	−127	1
LRLJ	35.47942	−117.68211	1315	−213	−127	1
LRLK	35.47942	−117.68211	1315	−213	−127	1
LRM	35.47737	−117.69000	1222	−5	−1	−9
LRR	34.52629	−118.02867	880	−30	14	−15
LTC	33.49378	−115.07700	275	−523	580	134
LUC	34.45476	−116.96474	855	10	−1462	−13
MAR	35.00260	−119.34022	411	−11	0	−17
MDA	33.91380	−117.00067	820	−84	33	−19
MIR	33.41621	−116.08171	30	2	−6	13
MLL	34.09125	−116.93713	1480	12	0	−10
MWC	34.22368	−118.05827	1696	−35	−82	−11
NW2	33.08732	−115.69266	−100	360	−40	−15
OLY	33.43142	−117.11806	446	−4	−23	−9
PAS1	34.14844	−118.17113	257	83	−111	5
PAS2	34.14844	−118.17113	257	83	−111	5
PAS3	34.14844	−118.17113	257	83	−111	5
PASLE	34.14844	−118.17117	257	83	−107	5
PASLN	34.14844	−118.17117	257	83	−107	5
PASLZ	34.14844	−118.17117	257	83	−107	5
PAS	34.14844	−118.17117	257	83	−107	5
PCF	34.05304	−117.79144	226	18	−5	−107
PEC	33.89198	−117.16135	582	−12	49	−10
PEMZ	34.16689	−117.87009	777	51	−37	−321
PEM	34.16689	−117.87009	777	51	−37	−321
PKM	34.89556	−119.82084	1673	29	102	−12
PLE	34.96857	−119.06899	1050	−7	10	−11
PLME	33.35361	−116.86265	1660	−24	17	−13
PLMN	33.35361	−116.86265	1660	−24	17	−13
PLM	33.35361	−116.86265	1660	−24	17	−13
PLSE	33.79530	−117.60906	1181	26	21	−49
PLSI	33.79530	−117.60906	1181	26	21	−49
PLSJ	33.79530	−117.60906	1181	26	21	−49
PLSK	33.79530	−117.60906	1181	26	21	−49
PLSN	33.79530	−117.60906	1181	26	21	−49
PLS	33.79530	−117.60906	1181	26	21	−49
PLT	32.73123	−114.73012	26	2	4	−15
POBZ	33.68700	−116.92399	974	−31	−12	−16
POB	33.68699	−116.92402	974	−30	−10	−16
PSP	33.79371	−116.54968	162	18	4	−12
PTD	34.00443	−118.80686	7	−26	−30	−13
PVPZ	33.78939	−118.40199	109	34	106	4
PVR	33.75237	−118.37171	153	−37	34	−17
PYR	34.56784	−118.74190	1209	18	−57	−6
QAL	34.74909	−118.71518	1232	64	−32	−19
RAYE	34.03749	−116.81306	2369	−124	100	−70
RAYN	34.03749	−116.81306	2369	−124	100	−70
RAYZ	34.03749	−116.81306	2369	−124	100	−70
RAY	34.03749	−116.81306	2369	−124	100	−70
RCPE	33.77731	−118.13343	−26	6	−6	−9
RCPN	33.77731	−118.13343	−26	6	−6	−9
RCPZ	33.77731	−118.13343	−26	6	−6	−9
RCP	33.77730	−118.13345	−32	6	−6	−189
RMME	34.64384	−116.62438	1777	−71	−9	−16
RMMI	34.64384	−116.62438	1777	−71	−9	−16
RMMJ	34.64384	−116.62438	1777	−71	−9	−16
RMMK	34.64384	−116.62438	1777	−71	−9	−16
RMMN	34.64384	−116.62438	1777	−71	−9	−16
RMMZ	34.64384	−116.62438	1777	−71	−9	−16
RMM	34.64384	−116.62438	1777	−71	−9	−16

Table 8—*Continued*

Station	Latitude (°)	Longitude (°)	Height (m)	ΔN (m)	ΔE (m)	ΔH (m)
RMR	34.21283	−116.57630	1663	3	15	−5
RUN	32.97222	−114.97809	116	3	15	−12
RVR	33.99351	−117.37545	232	−16	−34	−16
RYS	34.64341	−119.35224	1807	−8	−28	−9
SAD	34.08087	−118.66554	715	16	−28	−29
SAT	33.70796	−117.89143	−420	8	−6	−391
SBB	34.68817	−117.82501	796	18	−76	−8
SBCE	34.44076	−119.71492	61	101	64	−15
SBCN	34.44076	−119.71492	61	101	64	−15
SBC	34.44076	−119.71492	61	101	64	−15
SBK	35.07914	−117.58287	851	−33	63	−13
SBPI	34.23236	−117.23488	1843	−18	−70	−12
SBPJ	34.23236	−117.23488	1843	−18	−70	−12
SBPK	34.23236	−117.23488	1843	−18	−70	−12
SBPZ	34.23236	−117.23488	1843	−18	−70	−12
SC1	34.01916	−118.28598	17	−14	−17	−67
SCC	34.94094	−120.17297	565	−142	6	1
SCD	34.36841	−119.34467	183	29	−2	−14
SCIE	32.97919	−118.54698	178	95	−49	−8
SCIN	32.97919	−118.54698	178	95	−49	−8
SCI	32.97919	−118.54698	178	95	−49	−8
SCY	34.10647	−118.45533	250	−30	29	−9
SDL	35.37652	−117.88838	638	441	78	74
SDW	34.60953	−117.07593	1125	−37	86	14
SGL	32.64933	−115.72638	75	−8	26	−14
SILZ	34.34802	−116.82746	1698	−17	−1	−12
SIL	34.34802	−116.82746	1698	−17	−1	−12
SIM	35.35017	−119.99653	578	35	−119	579
SIP	34.20453	−118.78073	694	−56	−1762	−40
SKY	33.77575	−117.10712	774	64927	15302	264
SLC	34.49593	−119.71435	1164	63	−2	−17
SLG	34.10946	−119.06496	381	561	−6	−12
SLP	34.55353	−120.39819	113	661	−278	−23
SLT	33.26488	−115.92420	−83	1	23	−14
SME	33.82288	−117.35623	466	−19	8	−23
SMO	33.53561	−116.46239	2403	30	−6	−12
SND	35.14264	−118.30286	1294	39	−14	−19
SNRE	32.86184	−115.43602	−63	7	−146	−15
SNRN	32.86184	−115.43602	−63	7	−146	−15
SNRZ	32.86184	−115.43602	−63	7	−146	−15
SNR	32.86184	−115.43602	−63	7	−146	−15
SNS	33.43239	−117.55047	117	−74	123	−12
SRT	35.69235	−117.75051	667	−59	30	−11
SS2E	34.20734	−117.50039	1574	40	−9	−9
SS2N	34.20734	−117.50039	1574	40	−9	−9
SS2	34.20734	−117.50039	1574	40	−9	−9
SSCE	33.99546	−119.63513	413	−85	100	−2
SSCN	33.99546	−119.63513	413	−85	100	−2
SSC	33.99546	−119.63513	413	−85	100	−2
SSN	33.24494	−119.50737	217	−25	16	−5
STOE	34.69201	−117.11726	1145	0	−5	4
STOI	34.69201	−117.11726	1145	0	−5	4
STOJ	34.69201	−117.11726	1145	0	−5	4
STOK	34.69201	−117.11726	1145	0	−5	4
STON	34.69201	−117.11726	1145	0	−5	4
STOZ	34.69199	−117.11726	1145	3	−5	4
STO	34.69199	−117.11727	1145	3	−4	4
STT	34.78904	−118.46361	796	−58	84	−9
SUN	34.21048	−117.69394	1652	24	10	−13
SUP	32.95537	−115.82547	177	−13	81	−6
SWM	34.71605	−118.58362	1184	31	8	−7
SYP	34.52780	−119.97834	1253	−69	−34	7
SYS	32.57936	−116.91486	181	42	241	48

Table 8—*Continued*

Station	Latitude (°)	Longitude (°)	Height (m)	ΔN (m)	ΔE (m)	ΔH (m)
TABZ	34.38245	−117.68191	2250	−66	37	−10
TAB	34.38245	−117.68191	2250	−66	37	−10
TCCJ	33.99465	−118.01397	195	−13	28	58
TCC	33.99465	−118.01397	195	−13	28	58
TEJ	35.23107	−118.68878	844	−138	−143	−252
THC	34.90853	−118.66443	1688	15	6	−13
TINE	37.05422	−118.23009	1164	81	78	−6
TINN	37.05422	−118.23009	1164	81	78	−6
TIN	37.05422	−118.23009	1164	81	78	−6
TJR	35.02722	−118.74373	398	30	33	−2
TMB	35.08693	−119.53548	988	43	−7	−10
TOW	35.80885	−117.76493	653	−59	−83	−381
TPC	34.10564	−116.04939	686	25	−6	−11
TPO	34.87883	−118.22864	769	0	10	−13
TPR	34.09285	−118.58780	335	−17	87	−382
TWLE	34.27827	−118.59548	352	9	11	−16
TWLN	34.27827	−118.59548	352	9	11	−16
TWL	34.27827	−118.59548	352	9	11	−16
UPLE	34.14817	−117.69940	516	131	−8	−5
UPLI	34.14817	−117.69940	516	131	−8	−5
UPLJ	34.14817	−117.69940	516	131	−8	−5
UPLK	34.14817	−117.69940	516	131	−8	−5
UPLN	34.14817	−117.69940	516	131	−8	−5
UPLZ	34.14817	−117.69940	516	131	−8	−5
UPL	34.14817	−117.69940	516	131	−8	−5
VETE	34.29678	−118.02833	1757	−10	−845	−14
VETI	34.29678	−118.02833	1757	−10	−845	−14
VETJ	34.29678	−118.02833	1757	−10	−845	−14
VETK	34.29678	−118.02833	1757	−10	−845	−14
VETN	34.29678	−118.02833	1757	−10	−845	−14
VETZ	34.29678	−118.02833	1757	−10	−845	−14
VET	34.29678	−118.02833	1757	−10	−845	−14
VG2	33.83254	−116.81041	1465	−73	40	−25
VPD	33.81596	−117.76338	147	−102	81	−10
VST	33.15585	−117.23200	76	97	−44	−11
WAS	35.73770	−118.55743	1828	49	−39	1
WBM	35.60839	−117.89049	892	−44	−32	−9
WBS	35.53671	−118.14035	1902	31	0	−12
WCH	35.87887	−118.07405	2461	456	−133	−26
WCS	36.02702	−117.76761	1135	−78	−6	−33
WCX	35.71155	−117.59448	654	−117	−546	−26
WHF	35.69513	−118.35183	859	113	223	1
WHS	36.10508	−117.76177	1411	−11	−22	−4
WHV	35.50989	−118.51904	971	10	31	−7
WI2E	33.27614	−115.58154	−97	28	10	−18
WI2	33.27614	−115.58154	−97	28	10	−18
WISE	33.27583	−115.59542	−102	25	154	−13
WIS	33.27586	−115.59540	−102	23	152	−13
WJP	35.41094	−118.48196	1090	−12	38	−10
WLH	36.15243	−118.31312	2645	−14	52	−8
WLK	33.05135	−115.49193	−82	6	46	−14
WMF	36.11774	−117.85484	1513	−29	103	6
WNM	35.84220	−117.90616	923	68	43	−14
WOF	35.53545	−118.71352	1306	22	13	−8
WOR	35.69563	−118.24246	795	94	−36	0
WRC	35.94896	−117.64787	930	188	−103	−27
WRVE	36.00783	−117.89056	1039	−2	−56	−13
WRVJ	36.00783	−117.89056	1039	−2	−56	−13
WRVK	36.00783	−117.89056	1039	−2	−56	−13
WRVN	36.00783	−117.89056	1039	−2	−56	−13
WRV	36.00783	−117.89056	1039	−2	−56	−13
WSC	35.70429	−117.88751	853	2	14	−14
WSH	35.59962	−117.49265	764	3666	12	−28

in routine earthquake location by the SCSN as of 1 January 1994 (Wald *et al.*, 1994).

Acknowledgments

Funding for this project was provided through a cooperative agreement by USGS Grant Number 1434-92-A0960 and the Southern California Earthquake Center, SCEC Contribution Number 110. The GAMIT processing software was provided by MIT. Eric Calais provided basic instruction for the GAMIT software. Yehuda Bock provided the PGGA data processed by Peng Fang, and Keith Stark helped access it. Ken Hudnut, Duncan Agnew, Joann Stock, Paul Segall, Dave Jackson, Hiroo Kanamori, and Yehuda Bock loaned the GPS receivers. Gary Cone, Bob Cone, Bill Curtis, Darryl Baisley, Scott Lydeen, and Tom Heaton of the USGS and Dave Johnson at CIT helped with the field work for the SCSN. Michelle Robertson and Lanny Fields helped with the field work for the USC stations. Adam Edelman, Harold Magistrale, Aaron Martin, Mike Sleymor, and Rasool Anooshepoor helped with the field work for portable stations. Damien Sullivan helped process the GPS data.

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Manuscript received 19 January 1994.